

PTO 04-2586

CY=JA DATE=19870702 KIND=A
PN=62-148850

METHOD FOR DETECTING SOLIFIED STATE OF BILLET
[CHUHEN NO GYOKO JOTAI KENSHUTSU HOHO]

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UNITED STATES PATENT AND TRADEMARK OFFICE
Washington, D.C. April 2004

Translated by: FLS, Inc.

PUBLICATION COUNTRY	(10): JP
DOCUMENT NUMBER	(11): 62148850
DOCUMENT KIND	(12): A
PUBLICATION DATE	(43): 19870702
PUBLICATION DATE	(45):
APPLICATION NUMBER	(21): 60291455
APPLICATION DATE	(22): 19851224
ADDITION TO	(61):
INTERNATIONAL CLASSIFICATION	(51):
DOMESTIC CLASSIFICATION	(52): G01N 29/00; B22D 11/16
PRIORITY COUNTRY	(33):
PRIORITY NUMBER	(31):
PRIORITY DATE	(32):
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TITLE	(54): METHOD FOR DETECTING SOLIFIED STATE OF BILLET
FOREIGN TITLE	[54A]: CHUHEN NO GYOKO JOTAI KENSHUTSU HOHO

1. Title of the Invention

Method for Detecting Solidified State of Billet

2. Claim(s)

(1) A method for detecting the solidified state of a billet wherein a transverse ultrasonic wave transmitted into a billet in an electromagnetic method makes use of the residual molten metal inside the billet so as to detect the solidified state of the billet; said method for detecting the solidified state of a billet characterized by simultaneously transmitting a longitudinal ultrasonic wave and a transverse ultrasonic wave in an electromagnetic method, receiving the longitudinal ultrasonic wave and transverse ultrasonic wave having transmitted through the billet in an electromagnetic method to find the ratio of the amplitude of the transmitted transverse ultrasonic wave and the amplitude of the transmitted longitudinal ultrasonic wave.

3. Detailed Specifications

(Field of Industrial Application)

The present invention pertains to a method for detecting the solidified state of a billet, and in particular, it relates to an improvement of a method for detecting the solidified state of a billet, which is ideal for use while detecting the solidified state of a continuously cast billet, and detects the solidified state of the billet by making use of the fact that a transverse ultrasonic wave that has transmitted through a billet in an electromagnetic method does not transmit through the residual molten

*Number in the margin indicates pagination in the foreign text.

metal inside the billet.

(Prior Art)

The continuous casting of molten metal is performed by pouring molten metal 14 into a template 12 having a prescribed cross-sectional shape from a tundish 10, as shown in Fig. 8, and consecutively withdrawing it as a billet 16 comprising solidified metal 18 and residual molten metal 19 from the lower region of the template 12.

Although the aforesaid billet 16 has a thick layer of unsolidified residual molten metal 19 therein right after being withdrawn from the template 12, this residual molten metal 19 gradually solidifies from the outside by cooling after that to get the solidified metal 18, and before long, it is completely solidified.

During such continuous casting of molten metal, it is very important to improve the quality of the billet 16 and its productivity to constantly monitor the solidified state of the billet as to whether residual /284 molten metal 19 is present inside the billet 16 at a prescribed position in continuous casting by preventing accidents like breakout, in which the internal molten metal covers the solidified layer and then is exposed to the outside, and optimizing the relation between the withdrawal speed the billet 16 and the cooling of the billet 16.

A method for observing the transmittability of the transverse ultrasonic wave has been known in the past for the above method for detecting whether residual molten metal 19 is present inside the billet 16. This method makes use of the fact that the transverse wave does not propagate

through a liquid. That is, the part inside the billet through which the transverse ultrasonic wave passes can be judged as completely solidified and the part through which the transverse ultrasonic wave does not pass through can be judged as having residual molten metal present therein.

In combination with this method is widely known to be effective a method for transmitting/receiving electromagnetic ultrasonic waves, like the method recently disclosed in Tokkai No. 52-130422 for detecting a perfect solidification position in a billet by transmitting and receiving an ultrasonic wave to/from an object with a high temperature or a rough surface.

This method detects the perfect solidification position in a billet from the transmittability of this transverse ultrasonic wave perpendicular to the billet by allowing the transverse ultrasonic wave to transmit into the billet in an electromagnetic method.

(Problems to be Solved by the Invention)

Nevertheless, in this method disclosed in Tokkai No. 52-130422, there were problems as follows. That is, in the method for transmitting/receiving an electromagnetic ultrasonic wave, the vibrational intensity of the ultrasonic wave in the billet (in the case of transmission) or the efficiency for receiving the ultrasonic vibration (in the case of reception) depends largely on the distance between the billet and the transmission element or receiving element (hereinafter referred to as "lift-off"). The influence of a fluctuation in lift-off is manifested as such with the receiving intensity of the ultrasonic wave by the receiving element. Consequently, when a transverse ultrasonic wave transmission signal is not obtained

by the receiving element, it cannot be determined if this is because there is residual molten metal inside the billet or if it is due to the influence of a fluctuation in lift-off, so it cannot be concluded that there is residual molten metal inside the billet. When an accident or damage occurs in a portion of an electromagnetic ultrasonic transceiver comprising a transmission element, receiving element, magnetic field generator, electric pulse generator, amplifier, and the like, the intensity of the transmission signal of the transverse ultrasonic wave weakens, or a state develops in which the transmitted signal of the transverse ultrasonic wave disappears.

But complete differentiation of a decrease or disappearance of the transmitted signal of the transverse ultrasonic wave cannot be wholly used since there is residual molten metal inside the billet. Consequently, the method disclosed in Tokkai No. 52-130422 had a problem because it could not be concluded that residual molten metal was present inside the billet due to the fact that the transmitted signal of the transverse ultrasonic wave decreased or disappeared.

(Object of the Invention)

The present invention was achieved in order to solve the aforesaid conventional problems, and it is an object to obtain a method for detecting the solidified state of a billet in which the solidified state of a billet can be detected stably and reliably as to whether residual molten metal is present inside the billet, regardless of a fluctuation in lift-off or an accident or damage to the means for transmitting/receiving an ultrasonic wave.

(Means for Solving the Problems)

The present invention achieves the aforesaid object in a method for detecting the solidified state of a billet wherein a transverse ultrasonic wave transmitted into a billet in an electromagnetic method makes use of the residual molten metal inside the billet so as to detect the solidified state of the billet by simultaneously transmitting a longitudinal ultrasonic wave and a transverse ultrasonic wave in an electromagnetic method, receiving the longitudinal ultrasonic wave and transverse ultrasonic wave having transmitted through the billet in an electromagnetic method to find the ratio of the amplitude of the transmitted transverse ultrasonic wave and the amplitude of the transmitted longitudinal ultrasonic wave.

(Effects)

Figure 1 shows a basic constitution of the present invention.

The outer wall of the residual molten metal 19 forms the solidified metal 18 due to cooling, and an electromagnetic ultrasonic wave transmission element 20 is arranged on one side of the billet 16 and an electromagnetic ultrasonic wave receiving element 22 is arranged on the other side. Since an ultrasonic wave is allowed to transmit into the billet 16 by means of the aforesaid ultrasonic wave transmission element 20, a current is supplied to the ultrasonic wave transmission element 20 by a magnetic field generating power source 24, and moreover, an electric signal is supplied to a transmission coil (not shown) of the ultrasonic wave /285 transmission element 20 by means of a transmission signal generator 26.

In order to receive the ultrasonic wave signal having transmitted through the billet 16 by means of the ultrasonic wave receiving element

22, a magnetic field generation current is supplied to the ultrasonic wave transmission element 20 by a magnetic field generating power source 28, the ultrasonic wave signal received by the ultrasonic wave receiving element 22 and converted to an electric signal is amplified by an amplifier 30, and displayed on, e.g., an oscilloscope 32.

As shown in Fig. 2, herein, if residual molten metal 19 is not present in the part where the ultrasonic wave is transmitting through, both the longitudinal wave and transverse wave transmit through the billet 16, and an ultrasonic wave signal waveform is obtained on the oscilloscope 32, as shown in Fig. 3. Meanwhile, as shown in Fig. 4, if residual molten metal 19 is present in the part where the ultrasonic wave is transmitting through, the transverse wave cannot propagate through the liquid; hence, only the longitudinal wave transmits through the billet 16, and as shown in Fig. 5, an ultrasonic wave signal waveform is obtained.

Consequently, in the ultrasonic wave signal waveform received by the ultrasonic wave transmission element 20, the ratio A_t/A_l of the amplitude A_l of the longitudinal transmitted wave and the amplitude A_t of the transverse transmitted wave is obtained. When this ratio is less than a certain threshold and it is judged that the residual molten metal 19 is present inside the billet 16, the solidified state of the billet 16 can be detected.

As previously stated, in the method for transmitting/receiving an electromagnetic ultrasonic wave, although the intensity of the ultrasonic wave transmitted into the billet 16 by means of the ultrasonic wave transmission element 20 and the ultrasonic wave receiving efficiency by

the ultrasonic wave receiving element 22 depends largely on the lift-off corresponding to the billet 16 of the respective ultrasonic wave transmission element 20 and the ultrasonic wave receiving element 22, according to the method of the present invention, as described above, the longitudinal ultrasonic wave and transverse ultrasonic wave are transmitted simultaneously into the billet 16, and in order to receive the longitudinal ultrasonic wave and transverse ultrasonic wave by means of, e.g., the same ultrasonic wave receiving element 22, the same effect of a fluctuation in lift-off is manifested with the amplitudes of the longitudinal and transverse waves in the received signal. Consequently, the effect of a fluctuation in lift-off is not manifested at all with the ratio A_t/A_l of the amplitude A_l of the longitudinal transmitted wave and the amplitude A_t of the transverse transmitted wave. Since the transmittability of the transverse wave is substantially constant, regardless of the presence of residual molten metal 19 in the billet 16, the transmittability of the transverse wave in the billet 16 can be evaluated correctly according to the amplitude ratio A_t/A_l . Furthermore, when the amplitude of the longitudinal transmitted wave is lower than a certain threshold, a judgment of excessive lift-off or a machinery accident may be issued right away.

As described above, the problems in Tokkai No. 52-130422 are solved in one fell swoop.

(Practical Examples)

In reference to the drawings, practical examples of a device for detecting the solidified state of a continuously cast billet, in which the method for detecting the solidified state of a billet pertaining to

the present invention has been used, will now be described in detail.

The present practical example is constituted as shown in Fig. 6, and as in Fig. 1, the electromagnetic ultrasonic wave transmission element 20 is arranged on one side of the billet 16 and the electromagnetic ultrasonic wave receiving element 22 on the other side of the billet 16.

The aforesaid ultrasonic wave transmission element 20 and the ultrasonic wave receiving element 22 both are capable of simultaneously transmitting/receiving a longitudinal wave and transverse wave by means of one receiving element or transmission element, which is constituted as shown in detail in Fig. 7. In the drawing, 102 and 112 are magnetic field generation coils, which are connected to the same respective magnetic field generating power sources 24 and 28, as in Fig. 1 given above. 103 and 113 are magnetic field generation iron cores. Furthermore, 105 is a transmission coil, which is connected to a transmission signal generator 26. By supplying a DC current to the magnetic field generation coil 102 herein by means of the, e.g., magnetic field generating power source 24, a magnetic field is generated, as shown by the dashed line A. By conducting a pulse current generated by the damped vibration from, e.g., RLC resonance by combining the transmission signal generator 26 with the transmission coil 105, an induced current B is generated on the surface of the solidified metal 18, as shown in the drawing, and in accordance with Fleming's rule, due to the interaction between this induced current B and the magnetic field A, a Lorentz force is generated on the surface of the solidified metal 18. At this time, an induced current denoted by a in the induced

current **B** is induced on the surface of the solidified metal 18 from a part of the transmission coil 105 denoted by **a**. But due to the interaction between the induced current **Ba** and the magnetic field **A**, a Lorentz force shown by the arrow **Ca** is generated. This Lorentz force produces a /286 longitudinal wave that advances in the direction of the arrow **D**. Although an induced current denoted by **b** of the induced current **B** is induced on the surface of the solidified metal 18 from a part denoted by **b** of the transmission coil 105, a Lorentz force denoted by the arrow **Cb** is generated on the surface of the solidified metal 18 due to the interaction between this induced current **Bb** and the magnetic field **A**. This Lorentz force produces a transverse wave that advances in the direction of the arrow **D** in the same manner. Thus, the longitudinal wave and transverse wave may be transmitted into the billet 16 simultaneously by the one ultrasonic wave transmission element 20.

Then, the longitudinal wave and transverse wave that propagate in the direction of the arrow **D** and reach the surface on the opposite side of the billet 16 have impetuses denoted by arrows **Ea** and **Eb**. Due to the interaction between these impetuses and the magnetic field (dashed line) **F** by means of the ultrasonic wave receiving element 22, induced currents **Ga** and **Gb** are produced, mechanical vibration is converted to an electrical signal and detected by a receiving coil 115. Thus, the longitudinal wave and transverse wave may be received by the one ultrasonic wave receiving element 22.

The ultrasonic wave signal received by the aforesaid ultrasonic wave receiving element 22 and converted to an electric signal is inputted into the amplifier 30, as in Fig. 1. This amplifier 30 amplifies the inputted ultrasonic wave signal and subsequently outputs it to gate circuits 34A and 34B through two channels. The electric signals outputted to the gate circuits 34A and 34B are entirely the same.

The gate circuit 34A extracts a signal from the inputted signal according to the longitudinal wave and outputs it to a peak value detection circuit 36A. This peak value detection circuit 36A detects the amplitude A_l of the signal according to the inputted longitudinal wave and outputs it to an arithmetic processing apparatus 38. Another gate circuit 34B fetches a signal from the inputted signal according to the transverse wave and outputs it to a peak value detection circuit 36B. This peak value detection circuit 36B detects the amplitude A_t of the signal according to the inputted transverse wave and outputs it to the aforesaid arithmetic processing apparatus 38.

Besides judging the presence of residual molten metal 19 in the billet 16 by calculating the ratio (A_t/A_l) of the amplitude of the transverse ultrasonic wave and the amplitude of the longitudinal ultrasonic wave from the inputted amplitude A_l and A_t values and comparing this value with a threshold, the arithmetic processing apparatus 38 outputs an alarm signal to an annunciator 40, such as a buzzer, when the amplitude A_l of the longitudinal ultrasonic wave is lower than a predetermined level.

Moreover, in the aforesaid practical example, a magnetic field was used along a DC current as a magnetic field for transmitting and receiving the ultrasonic wave electromagnetically, but it can be a magnetic field from a permanent magnet, or a pulse-like magnetic field induced by conducting a large pulse-like current through a coil.

(Advantages of the Invention)

As described above, according to the present invention, regardless of a fluctuation in lift-off or an accident of or damage to an ultrasonic wave transmitting/receiving means, whether residual molten metal is present inside a billet may be detected stably and accurately. Consequently, the present invention has an outstanding advantage because it can be quite effectively utilized for preventing accidents like breakout in continuous casting of metals and for optimally controlling the withdrawal speed of a billet and the cooling conditions.

4. Brief Description of the Drawings

Figure 1 is a cross section showing a basic structure of a device for carrying out the method for detecting the solidified state of a billet pertaining to the present invention; Figure 2 is a cross section showing an example of a relative positional relation between residual molten metal inside a billet and the electromagnetic ultrasonic wave transmitting/receiving means for describing the principles of the present invention; Figure 3 is a graph showing an example of an ultrasonic wave reception signal waveform in the state in Fig. 2; Figure 4 is a cross section showing another example of a relative positional relation between residual molten metal in a billet and the ultrasonic wave

transmitting/receiving means; Figure 5 is a graph showing an example of an ultrasonic wave reception signal waveform in the state in Fig. 4; Figure 6 is a cross section showing a constitution of a practical example of a device for detecting the solidified state of a continuously cast billet employed in the present invention to include a partial block graph; Figure 7 is a cross section showing a constitution and the effects of the ultrasonic wave transmission element and receiving element used in the aforesaid practical example; and Figure 8 is a cross section showing an example of a constitution of a continuous casting machine for a metal billet.

16: billet; 18: solidified metal; 19: residual molten metal;
 20: ultrasonic wave transmission element; 22: ultrasonic wave /287
 receiving element; At: amplitude of transmitted longitudinal ultrasonic wave; A1: amplitude of transmitted transverse ultrasonic wave

Figure 1

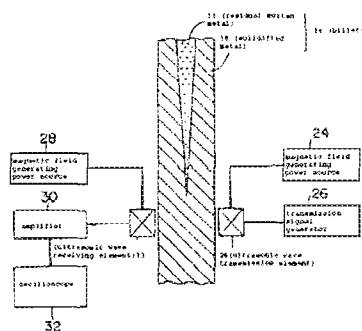


Figure 8

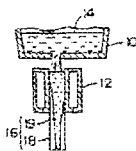


Figure 2

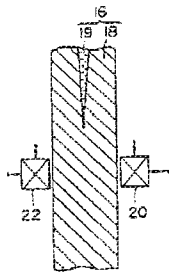


Figure 3

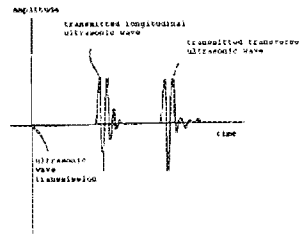


Figure 4

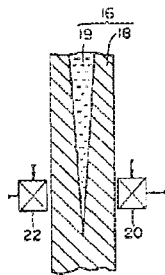


Figure 5

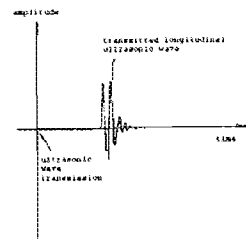
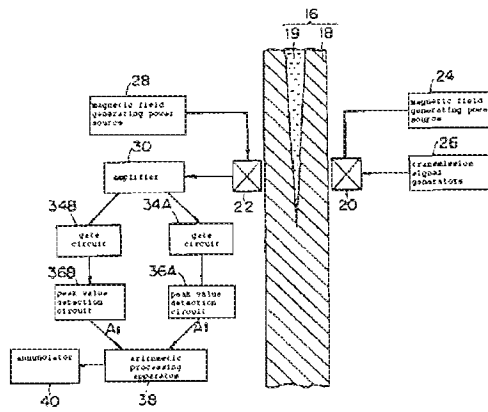


Figure 6



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Figure 7

